Chapter 2

Site Assessment

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This chapter will help the reader determine and define site conditions in order to select the most appropriate streambank-protection techniques. This approach requires identification and assessment of the mechanism of the failure, which, in turn, pinpoints the cause of bank erosion, critical to selecting an appropriate bank-protection treatment.

There are five main categories of mechanism of failure to consider:

1. toe erosion,
2. scour,
3. mass failure,
4. subsurface entrainment, and
5. avulsion and chute-cutoff potential.

The causes of erosion can be divided into two groupings:

1. site-based, or
2. reach-based (including watersheds).

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Mechanisms of failure can have both site-based and reach-based causes. For example, a common mechanism of failure is toe erosion caused by reduced vegetation along the bank (a site-based cause) in a reach that is filling with sediment and debris due to a downstream constriction, such as a bridge (a reach-based cause). Identifying reach-based causes typically requires multiple site investigations as well as broadening the view to a longer reach of the river. Historically, streambank protection has focused on site-specific concerns regarding an unstable bank, while neglecting reach or watershed-wide instabilities. By ignoring reach-based causes, streambank-protection designs can actually cause more damage than good. Indeed, they can cause additional failures such as channel flanking, structure undermining, or sediment deposition and burial of the treatment.

Site-based causes are addressed in this chapter, while reach-based causes are presented in Chapter 3, *Reach Assessment*. Both the site- and reach-based assessments are incorporated into the selection and design of streambank treatments in Chapter 5, *Identify and Select Solutions.*

Site- and reach-based causes affect the flow patterns in a stream, which are quantified using the concepts of "shear" and "scour." The calculation of shear and scour is site-specific, although they are influenced by reach-based causes. Shear and scour calculations can be found in Appendix E, *Hydraulics.* The role of shear and scour in streambank protection technique design is further described in Chapter 5. *Figure 2-1* depicts the assessment approach described in this chapter.

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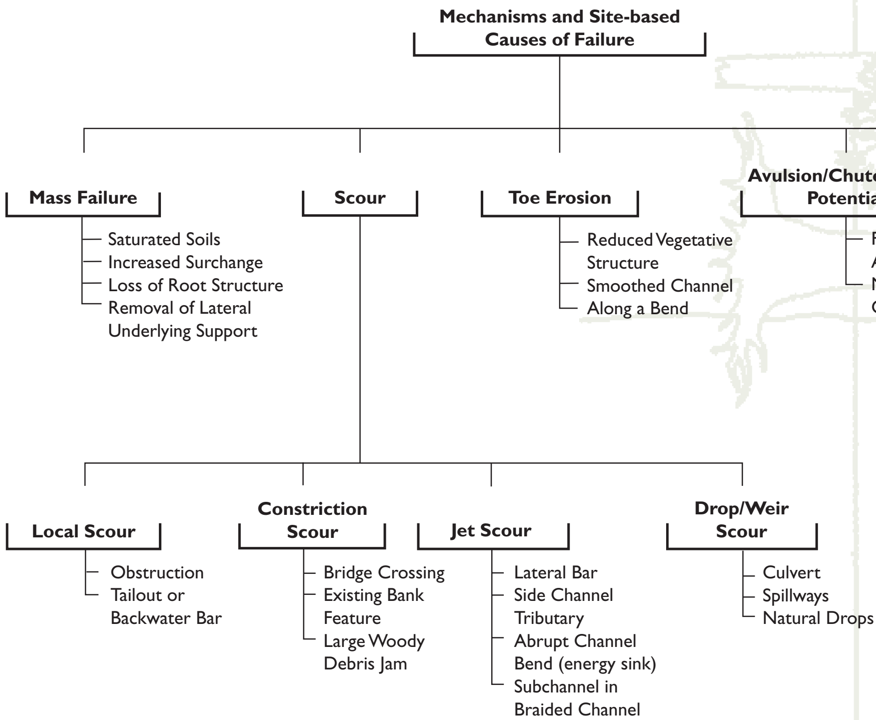

Figure 2-1. Site-assessment approach.

MECHANISMS OF FAILURE AND SITE-BASED CAUSES

A mechanism of failure is the physical process of erosion, which can be thought of as the problem you see on site. Observing the condition of the eroding streambank leads to identifying the mechanism of failure. Is the erosion occurring on one streambank, or on both banks simultaneously? Is the streambank eroding from the toe, causing larger blocks of material above the toe to fall into the river? Is there an obstruction in the channel? Is the erosion attacking the streambanks or is it also deepening the channel? Is the bed of the channel rising from a buildup of sediment? Does there appear to be a gradual shift toward the use of a secondary channel; are channels newly abandoned, or are scars forming where the channel used to go? Determining the mechanism of failure is accomplished by observing and evaluating on-site conditions such as: geologic elements and topography; soil types and horizons; flow patterns and degree of erosional force; vegetative growth, root depth and strength; streambank geometry; and sediment load.

A mechanism of failure is the physical process of erosion, which can be thought of as the problem you see on site.

The mechanism of failure may be due to either site-based or reach-based causes, or both. An example of a site-based cause of streambank erosion would be an obstruction in a stream (e.g., woody debris or an old car) causing localized changes to flow patterns that erode the adjacent streambank (local scour). Or, bank erosion could be due to a reach-based cause such as the migration of a channel bend or channel degradation. Sometimes, reach-based causes for failure contribute to site-based causes (and vice versa), so it's important to be alert to both possibilities, even when a particular cause seems obvious.

Identifying the mechanisms of failure and their causes typically occurs concurrently. Treating the mechanism of failure on site without identifying the underlying cause(s) is like taking an aspirin for a broken leg without examining the injury itself- you may be treating the symptoms, but you're not solving the problem. *Table 2-1* lists mechanisms of failure, site-based causes, reach-based causes and habitat considerations.

The physical process of erosion for most mechanisms of failure is called "entrainment." Entrainment is primarily a surface-erosion concern that can be quantitatively analyzed by using the concepts of shear and scour. This effort will contribute valuable information to the design of a successful streambank-protection project. Entrainment occurs as water flow picks up particles from:

- the entire streambank face or toe,
- the bed of the stream,
- a floodplain (causing rills and gullies), or
- subsurface flows seeping out of the bank (a phenomenon known as "piping").

Mechanism of Failure	Possible Site-Based Causes	Possible Reach-Based Causes (Chapter 3)	Habitat Considerations
Toe erosion	Reduced vegetative bank structure from land-clearing activities Smoothed channel Along a bend (bend scour)	Meander migration Aggradation Degradation	Removal of large trees limits stream-side cover and riparian benefits (food source, shade, nutrients, woody debris, wildlife). Smoothing a channel limits diversity and complexity, pools, spawning habitat, and woody debris. Erosion along a bend or adjacent to a mid-channel bar creates deep pools and overhanging streambanks for cover.
Local Scour	Obstruction Tailout or Backwater Bar	Not applicable	Scour creates deep pools and overhanging streambanks that fish use for cover. Scoured sediments deposited downstream from scour hole may create (or smother existing) spawning habitat.
Constriction Scour	Bridge Crossing Existing streambank feature Large woody debris jam	Not applicable	
Drop/Weir Scour	Weir, ledge or sill	Not applicable	
Jet Scour	Lateral bar Sidechannel or tributary Abrupt channel bend (energy sink) Subchannels in a braided channel	Not applicable	
Mass Failure	Saturated soils Increased surcharge Lack of root structure Removal of lateral/underlying support	Meander migration Aggradation Degradation	Increased sediment load may fill pools or smother spawning beds. May serve as source of spawning substrate.
Subsurface Entrainment	Groundwater seepage Rapid drawdown	Not applicable	Subsurface flows important for maintaining floodplain connectivity, base flows and temperature.
Avulsion/Chute Cutoff Potential	Floodplain activities, natural conditions	Aggradation, channel relocation, downstream constriction, braided channel, large storm event	Removal of riparian corridor limits stream-side cover.

Table 2-1. Mechanisms of failure, site- and reach-based causes, and habitat considerations.

It is important to identify subsurface flows on site as a separate category of entrainment because they require special methods for streambank protection treatment.

Flood events with return intervals greater than 10 years typically cause erosion, and the influence of these events on fish habitat is often overlooked. These events accumulate large woody debris, create scour pools, sort streambed gravel and reorganize habitat components into more complex conditions. The erosion imposed on channel margins through accumulation of woody debris provides channel stability and rejuvenates habitat.

In general, habitat that is reorganized annually or semi-annually fails to provide stable conditions sufficient to support fish and other organisms that have life histories of two to five years.[7,8] Habitat reorganized at a 10-year interval frequency, however, will likely provide each generation with a period of relative stability for growth, reproduction and recovery while also ensuring that natural processes sufficiently rejuvenate habitat conditions. Channel conditions that change frequently under short-return-interval floods are less beneficial to aquatic habitat than conditions that deform less frequently.

The physical process of erosion for most mechanisms of failure is called "entrainment." Entrainment is primarily a surface-erosion concern that can be quantitatively analyzed by using the concepts of shear and scour. This effort will contribute valuable information to the design of a successful streambank-protection project.

Evaluation of stream channels to determine the frequency and magnitude of channel adjustment should be part of any investigation into the causes of streambank erosion. Fish and other aquatic organisms have evolved specific behavioral, physiological and life-cycle adaptations for coping with physical conditions, periodic disturbance, as well as natural processes that occasionally modify and reorganize aquatic habitat. Flow events that cause extensive and widespread reorganization and redistribution of streambed materials, although critical in forming suitable habitats for fish and other aquatic organisms, are catastrophic for most stream benthic communities[1,2] and often affect survival of young stream fishes and colonizing macroinvertebrates.[3,4]

Recovery from these events may take up to several decades, depending upon the magnitude and intensity of the event, although in many cases fish communities are reported to recover in less than ten years.[5] Consequently, it is important that habitat be designed in a manner that replicates the frequency and magnitude of natural processes found in the stream being studied. Under too frequent or too intense of a habitat alteration regime, aquatic organisms will be adversely affected, and the suitability of available habitat for individual species will be diminished.[6]

Each of the five types of mechanisms of failure are described as follows:

Toe Erosion

Toe erosion occurs where water flow removes particles from the streambank and/or bed, undermines the toe and causes subsequent gravity collapse or sliding of overlying layers. In actuality, the term "toe erosion" is not entirely accurate, since the undermining may occur above the toe, depending upon site conditions. However, for the sake of simplicity, these guidelines will use the term toe erosion for all incidents of bank undermining and collapse due to water flow.

Toe erosion occurs either along a meander bend or a straight reach of channel. There are several site-based causes of toe erosion. Site-based causes of toe erosion include:

- Reduced vegetative bank structure: This is a disturbance of woody vegetation along the streambank and in the riparian area affecting the stability of the streambank in resisting erosion (see *Figure 2-2*). Plant roots on a streambank slope bind the soil together in a vertical and horizontal monolithic mass. The roots penetrate through the soil into firmer strata, thus anchoring the soil to the slope.[9] Disturbance of the woody vegetation is a common cause of streambank erosion[10] and is often directly associated with either urban development or agricultural management. It also occurs indirectly when there is a net lowering of the channel over time (a degrading channel). A degrading channel may lower the groundwater table below the root zone, desiccating the streambank, which, in turn, impairs the survival rate of the vegetation. Degradation is a reach-based process and is discussed further in Chapter 3.

Toe erosion occurs where water flow removes particles from the streambank and/or bed, undermines the toe and causes subsequent gravity collapse or sliding of overlying layers.

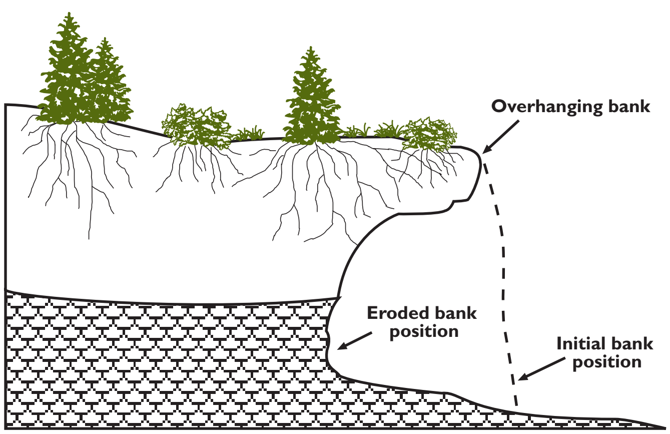

Figure 2-2. Toe erosion.

- Smoothed channel: This is a channel in which roughness elements have been removed, creating a channel with a reduced resistance to flow. Smoothed channels occur where woody debris has been removed, the channel has been dredged, or the streambank has been hardened (see *Figure 2- 3*). Once a channel is smoothed, it will have excess energy that is dissipated on the streambed and banks. The channel will adjust itself to dissipate this energy by increasing its channel length and decreasing its slope, or by degrading the channel bed (see Chapter 3). These adjustments trigger streambank erosion. To protect a streambank in a smoothed channel, it is best to add the roughness elements that were originally lost. Never add smooth structures, such as rock revetments to a smoothed channel. Doing so will further exacerbate the problem.

Figure 2-3. Smoothed channel.

- Along a bend: When flow moves along a bend, the thalweg (the deepest part of the streambed) shifts to the outer corner of the channel and pronounced bend scour occurs at the bend location. Bend scour results from spiraling flow patterns found in the meander bend of a stream (see page 2-18 for a discussion on spiraling flow). Sharper meander bends generate deeper scour than gentle bends. *Figure 2-4* shows the cross section of a channel in a straight reach and a bend. Note that the center of erosive force shifts from the bed of the channel to the outer corner of the channel. The maximum shear stress acting in a bend can be two or more times as high as the shear stress acting on the bed.[11] Therefore, when working along a bend, erosive force of the stream should be taken into account in selecting and designing a streambank treatment.

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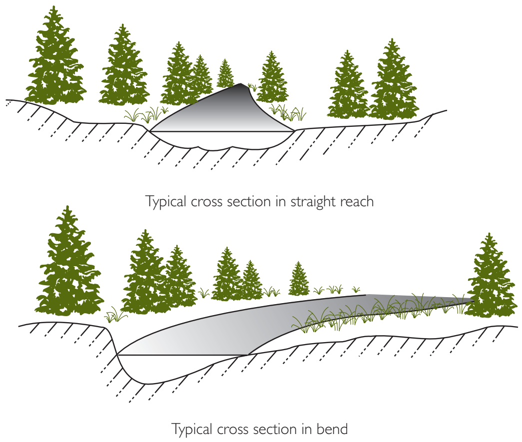

Figure 2-4. Typical channel cross sections in a straight reach and a bend.

- *Figure 2-5* contains a chart used to estimate the increased shear found in a bend, based on the radius of the bend and the width of the river. The method for calculating shear in a bend is to take the bed shear stress and multiply it by the bend factor. It becomes a judgment call based on the shape of the bend and how far up the streambank this maximum erosive force is acting. Each project and site will be different, but the designer will need to ensure that even the least erosion-resistant material used for streambank protection can withstand forces expected in the bend at the elevation of concern.

- Determining where the higher shear stress in a bend begins and ends, or where abrupt changes in the channel create higher shear stress longitudinally, can be identified by:

    - on-site observation of eroded points up stream and downstream,

    - theoretical book examples (*Figure 2-6*), or

    - reviewing sketches from available studies.

- Understanding the greater streambank erosional forces (shear) in river bends and at concentration points in the plan view is also helpful in preparing a streambank design. This information can be applied to selecting the beginning and end points of treatments along the project reach and selecting the point at which treatments can transition from more rigorous to less rigorous (or vice versa). A more detailed discussion about shear can be found beginning on page 2-16.

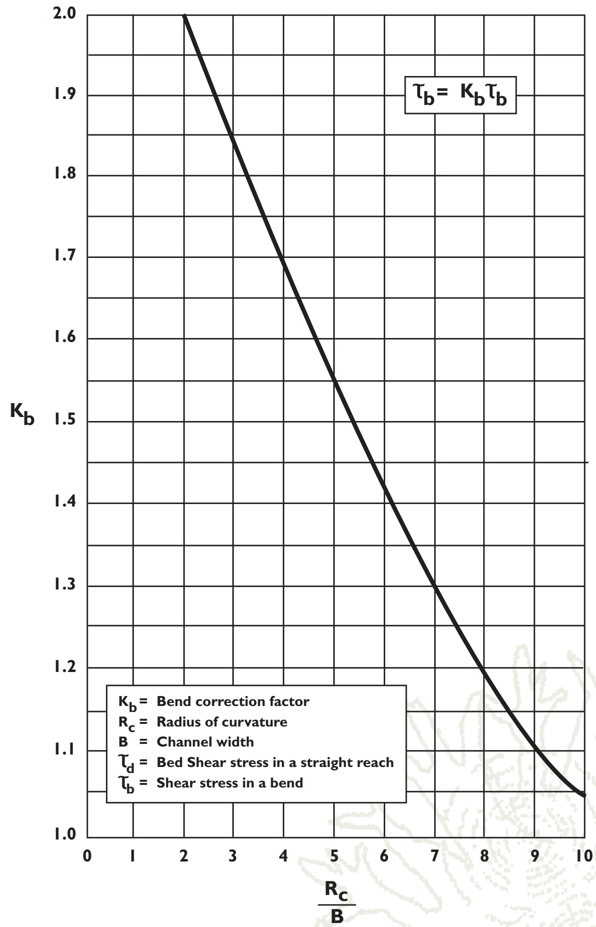

Figure 2-5. Chart showing increase in shear stress with an increase in the tightness of a bend.

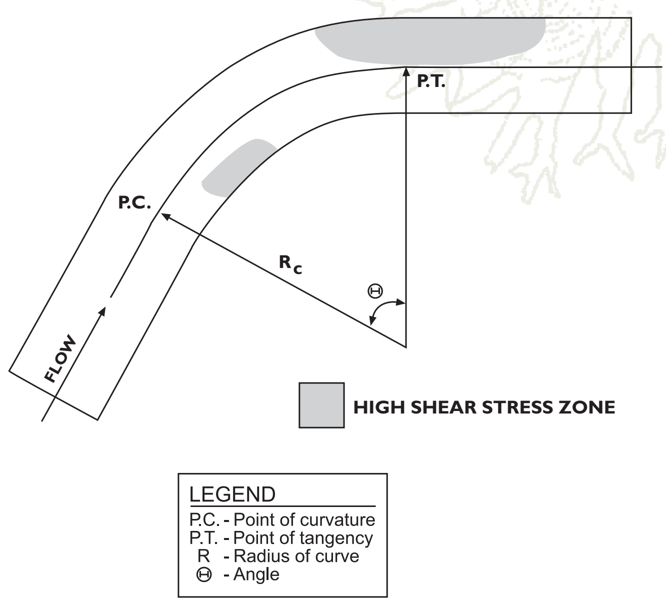

Figure 2-6. Shear stress distribution in a channel bend.

Scour

Scour is erosion at a specific location that is greater than erosion found at other nearby locations of the stream bed or bank. Scour can occur on both the channel bank and bed. Simons and Senturck[12] state that scour is "localized, as opposed to general bed degradation." For the purposes of these guidelines, there are four different kinds of scour to consider:

1. local,
2. constriction,
3. drop/weir, and
4. jet scour.

Scour is an essential contributor to the creation of fish habitat and its maintenance. Many fish-enhancement projects promote scour. It is not the extent or magnitude of the scour that promotes the best habitat, but the frequency of the scour activity. Sites absent of scour tend to provide less habitat than areas subject to moderately frequent scour events, given that intermediate-level disturbances promote aquatic diversity.[13, 14] Sites subject to very frequent scour have less habitat value than areas subject to moderately frequent scour events.

Scour is erosion at a specific location that is greater than erosion found at other nearby locations of the stream bed or bank.

Some scour will occur whenever abrupt changes in channel geometry are introduced to a system. Quantitative methods are available to estimate the depth of scour to be expected from different changes in the flow pattern, but it is first necessary to identify the type of scour. For example, the method for estimating constriction scour depth will not provide a realistic value if the erosion is produced by local scour. Methods for estimating scour depth are presented in Appendix E.

Local Scour: Local scour appears as discrete and tight scallops along the bankline, or as depressions in the stream bed. It is generated by flow patterns that form around an obstruction in a stream and spill off to either side of the obstruction, forming a horseshoe-shaped scour pattern in the streambed (*Figure 2-7*). When flow in the stream encounters an obstruction, for example a bridge pier, the flow direction changes. Instead of moving downstream, it dives in front of the pier and creates a roller (a secondary flow pattern) that spills off to either side of the obstruction. The resulting flow acceleration and vortices around the base of the obstruction results in a higher erosive force around the pier, which moves more bed sediment, thereby creating a scour hole.[15] The location around the pier is being scoured because the bed is eroded deeper at the pier than the bed of the stream adjacent to it. Scour is the key to providing excellent cover and holding habitat for fish.

Scour is an essential contributor to the creation of fish habitat and its maintenance. Many fish-enhancement projects promote scour.

Obstructions can be man-made or natural. Man-made obstructions include bridge piers or abutments. Natural obstructions include boulders, small collections of woody debris or midchannel bars. The extent of local scour

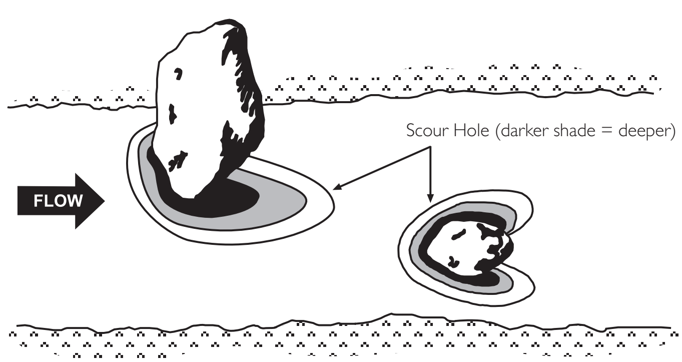

Figure 2-7. Local scour at boulder obstruction (plan view).

depends upon the relative size and location of the obstruction causing the scour. For example, scour formed around a single large tree that has fallen into the river will not extend a significant distance from the tree. As such, local scour is self-limiting and is generally not a high risk to streambank stability. When selecting streambank treatments to control or diminish localized scour, caution needs to be used installing flow realignment techniques (e.g., groins, barbs) upstream from the scoured streambank. Though they realign the flow away from the feature causing the scour, they may redirect the flow to the opposite streambank and cause erosion.

Midchannel bars can also create scour activity. These bars form in the wetted perimeter of the channel during high flow, and they separate the flow into two distinct channels at lower and moderate flows. Flow forced around a bar at low and moderate flows is concentrated against the streambank, increasing bank stress. Scour holes or trenches develop along the bankline, increasing the channel's cross-sectional area while creating spawning and rearing habitat.[16]

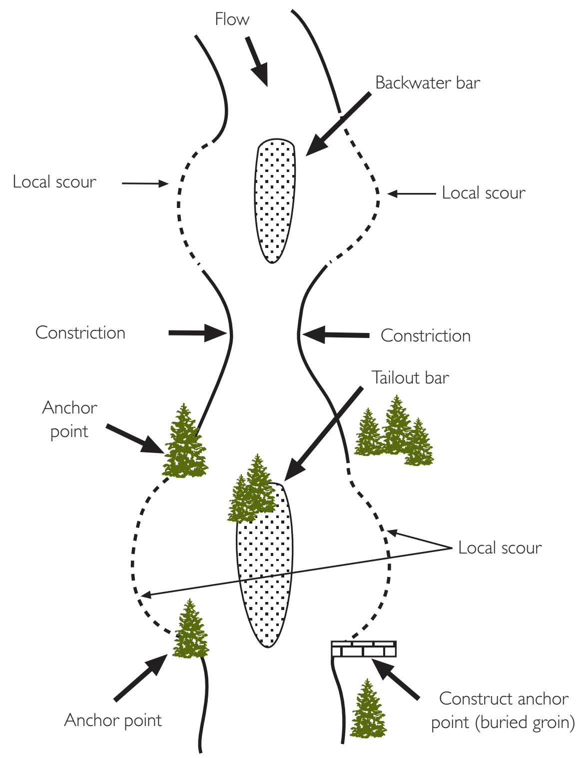

Figure 2-8. Tailout and backwater bars.

Tailout and backwater bars are common types of mid-channel bars. (*see Figure 2-8*). Tailout bars typically form directly downstream from a constriction, causing localized bed scour. The scoured sediment is transported and deposited downstream. Backwater bars form directly upstream from a constriction. As the water backs up at the constriction, the velocity decreases and sediment is deposited. Tailout or backwater bar formation is exacerbated when the supply of sediment to the site increases. If the sediment supply is a chronic problem throughout the reach, it is necessary to understand and deal with both the constriction and the upstream sediment supply to provide a long-term solution to the problem (a combination of site-based and reach-based causes). See Chapter 3 for more information about aggradation.

Constriction Scour: Constriction scour occurs when features along the streambank create a narrower channel than would normally form. Often the constricting feature is "harder" than the upstream or downstream bank and can resist the higher erosive forces generated by the constriction. Bedrock outcrops often form natural constrictions. The average velocity across the width of the channel increases, resulting in erosion across the entire bed of the channel at the constriction. The channel bed at the constricted section is deeper than channel bed upstream or downstream (*Figure 2-9*). Large woody debris jams or bridge crossings are common examples of features causing constriction scour. Bank features such as rocky points or canyon walls, overly narrow, man-made channel widths (e.g., with groins), or well-established tree roots on a streambank in smaller channels (sometimes referred to as "hard points") can cause constriction scour.

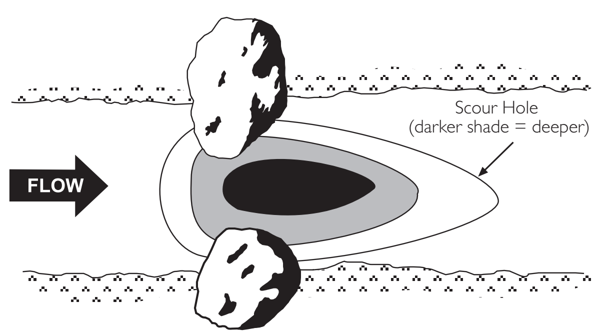

Figure 2-9. Constriction scour (plan view).

Drop/Weir Scour: Drop/weir scour is the result of water pouring over a raised ledge or a drop, creating a secondary flow pattern known as a roller. The roller scours out the bed below the drop (*Figure 2-10*). Energy-dissipation pools may result from drop scour. Perched culverts or culverts under pressure (during a high flow event), and discharge into a pool from spillways and from natural drops such as those found in a high-gradient mountain stream, are all causes of drop scour.

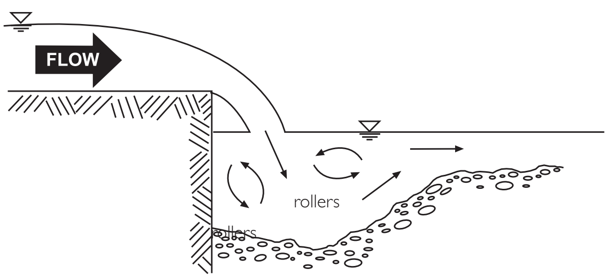

Figure 2-10. Typical drop or weir scour (section view).

Jet Scour: Jet scour occurs when flow enters the stream in the same manner as flow ejecting from the nozzle of a hose. The entering flow could be submerged, or could impact the water surface from above. The impact force from the flow results in jet scour on the streambed and/or bank. Lateral bars, subchannels in a braided or side channel or tributary, or an abrupt channel bend (energy sinks) can also create jet scour.

- Lateral bars are mid channel bars that typically occur directly downstream from a tight bend in the channel and are positioned diagonally in the channel. Jet scour forms when flow is redirected by the bar and focused directly into the adjacent streambank. (see *Figure 2-11*) Lateral bars form during bankfull events and scour occurs during the receding limb of the hydrograph and also during moderate flows. These bars are the result of natural channel processes or increased sediment supply. The cause of lateral bar formation should be determined during the reach assessment. Lateral bars create excellent spawning, cover and rearing habitat.

- Subchannels in a braided stream channel are another cause of jet scour. As water flows through these subchannels during low to moderate flows, the alignment of the subchannel may aim the flow directly at a bankline and cause jet scour (see *Figure 2-11*).

- When a high-energy side channel or tributary discharges into a main channel, the flow can be focused on the opposing streambank of the main channel (see *Figure 2-12*). This cause of jet scour is considered beneficial because the turbulent water attracts migrating salmon to their natal spawning tributaries and side channels.

- An energy sink is another cause of jet scour. When flow piles into the corner of a tight-radius bend, a scour pool forms (see *Figure 2-13*). The scour pool is the energy sink; it dissipates the energy of the entire momentum of the flow. Adequate volume in the energy sink should be provided for energy dissipation. An effective energy sink does not transfer carry-over energy downstream. Instead, it offers some protection to downstream banks and channel.

- Anchor points are a technique that can be used to stabilize an energy sink (see *Figure 2-7*). The use of anchor points requires an understanding of the balance between the need to preserve an energy sink while preventing further erosion. Anchor points are either natural (e.g., a tree or rock outcropping) or artificial hard structures (e.g., a rock trench) at the upstream and downstream end of an energy sink. They fix the upstream and downstream points of the sink, so volume cannot be gained by erosion in the

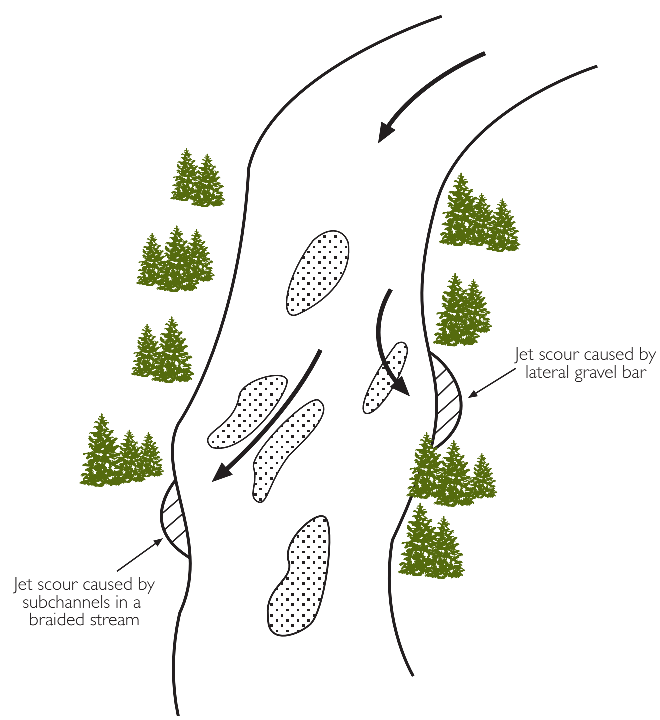

Figure 2-11. Jet scour caused by lateral gravel bar and braided subchannels (plan view).

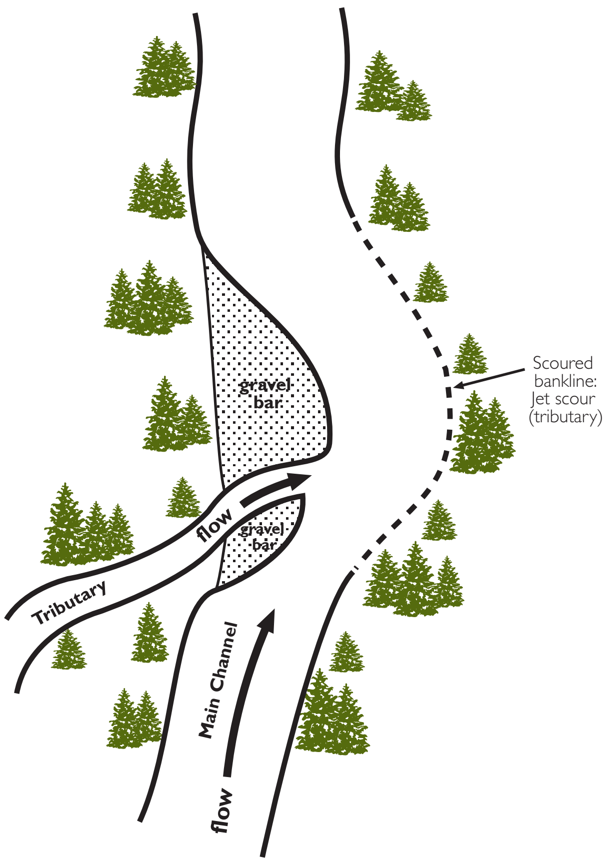

Figure 2-12. Jet scour caused by tributary discharge.

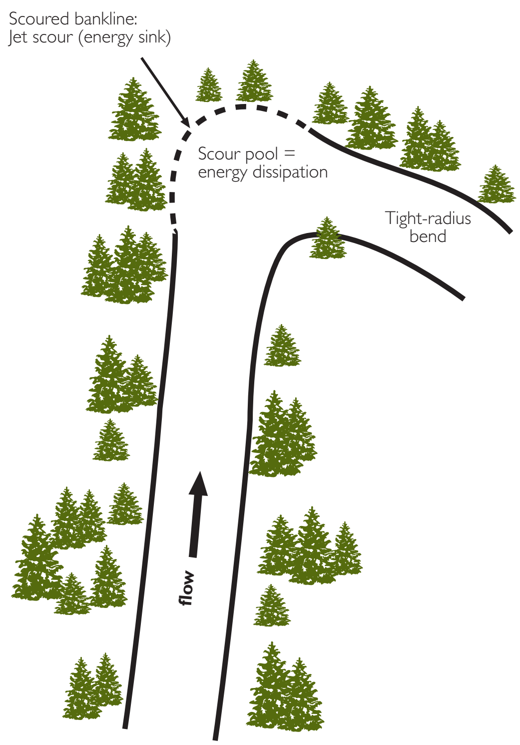

Figure 2-13. Jet scour caused by an energy sink.

upstream and/or downstream directions. By fixing these points, adequate dissipation volume is achieved by forcing erosion to occur either laterally or (preferably) vertically. Vertical erosion of the channel bed creates a deep pool, dissipating energy and creating habitat.

- Roughness elements are not the solution, as their scale often eliminates the energy dissipation volume of the energy sink. Straightening the bankline can destroy energy sinks. Instead, erosion should be allowed to continue until the energy sink has evolved to a mature and stable condition.

Subsurface Entrainment

Subsurface entrainment, or piping, occurs when subsurface flow picks up soil particles until small tunnels develop (see *Figure 2-14*). These tunnels reduce the cohesion of soil layers, thereby causing slippage and switch ultimately streambank erosion. Groundwater seepage and water-level changes, such as rapid draw down, are common causes of subsurface entrainment.

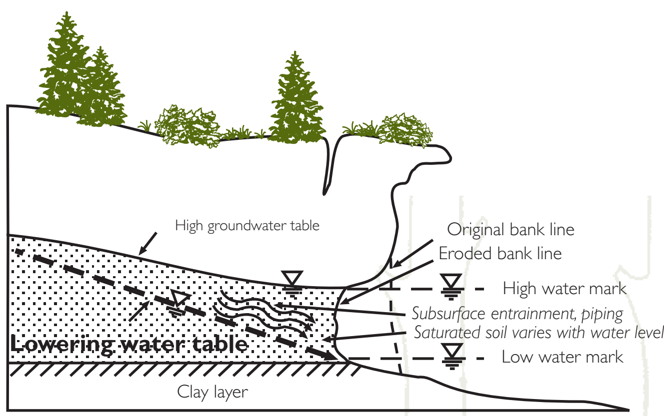

Figure 2-14. Subsurface entrainment, or piping.

Subsurface entrainment, or piping, occurs when subsurface flow picks up soil particles until small tunnels develop.

Mass Failure

Mass failure is the downward movement of large and intact masses of soil and rock.[9] It occurs when the down-slope shear stress (weight) exceeds the shear strength (resistance to weight) of the earth material. Shear stress is the driving force from gravity and/or loads acting on the slope. Shear strength is the characteristic of soil, rock and root structure that resists one unit of material sliding along another. Any cause that increases the shear stress or conversely decreases the shear strength will cause a mass failure. Ninety five percent of all mass failures are triggered by water saturating a slide-prone slope.[17]

Mass failure is the downward movement of large and intact masses of soil and rock.

When water saturates a slide-prone slope, it contributes to an increase in shear stress (it adds weight) and/or a decrease in shear strength (it lubricates). Mass failure results from a number of causes, including:

- rapid draw-down;
- manipulation of stream flows for storage, flood control or power;
- tidal effects; or
- seepage from springs and wetlands.

Bank erosion is also governed by other variables such as topography, geology and vegetation. Furthermore, mass failure can occur in combination with other mechanisms of failure, such as toe erosion or subsurface entrainment.

Understanding and identifying mass failure will assist in selecting appropriate streambank protection techniques. Mass failures are classified into five main groups:

1. falls,
2. topples,
3. slides,
4. spreads, and
5. flows.[17]

The majority of failures in the stream channels of Washington State are slides. There are two common types of slides:

1. rotational, and
2. translational.

Rotational slides have a curved and concave failure plane (*Figure 2-15*) and are generally deep-seated. They occur frequently in slopes ranging from 20 to 40 degrees and in homogeneous materials.[17] Translational slides are shallower than rotational slides and fail along well-defined, nearly planar surfaces (*Figure 2-16*). The failure surface is either soft clay of low strength, a silt layer sandwiched between two clay layers or bedrock.[11]

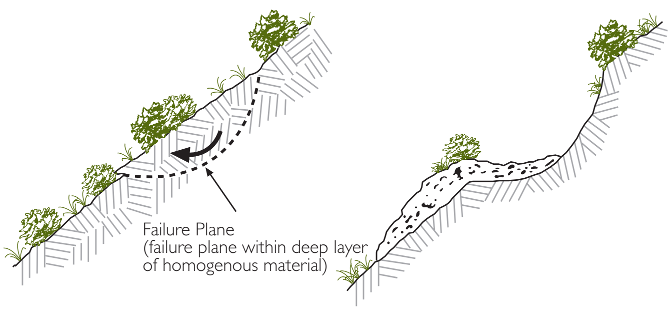

Figure 2-15. Rotational slide.

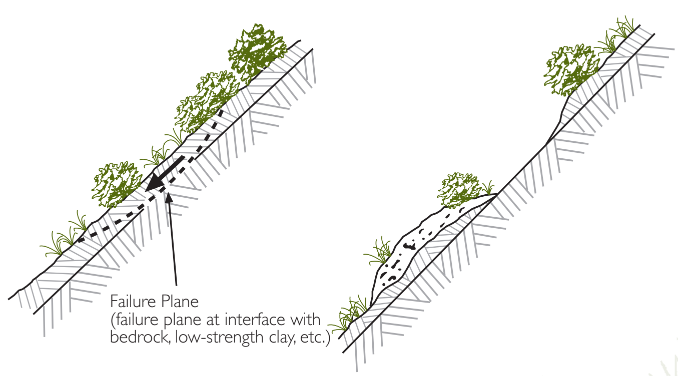

Figure 2-16. Transitional slide.

Slides can occur rapidly or gradually. There are a number of methods available for predicting the stability (or instability) of slopes. Visual indicators of slope stability, such as tilted and bowed trees or scarps, are useful to identify a slide that has been moving gradually over a number of years. Such slides may be reactivated by minor disturbances. Other stability or instability indicators include an over-steepened slope, removal of vegetation, cracks in the ground surface, springs and inherently weak soils.

Because mass failure can be deep-seated in the streambank, surface bank treatments may not solve the problem. For example, although vegetation is an effective surface-protection treatment, it cannot address deep-seated failure because of the limited rooting depth of plants. Therefore, solutions to mass failure along stream channels may involve surface bank treatments based on shear and scour concepts and geotechnical analysis. A geotechnical analysis identifies the need for interior drains, penetrating bank reinforcement, development of channel margins for debris flow chutes, or entire channel relocation. Streambank instability related to subsurface flows often requires additional drainage or corrections addressing the source of internal flows.

Avulsion and Chute-Cutoff Potential

An avulsion is a significant and abrupt change in channel alignment resulting in a new channel across the floodplain (*see Figure 2-17*). An avulsion is caused by concentrated overland flow, headcutting and/or scouring a new channel across the floodplain, leading to a major channel change. Prior to an avulsion, scour holes, headcuts and rills/gullies will be apparent in the floodplain. Avulsions occur during large storm events where there is substantial overland flow to erode the floodplain.

An avulsion is a significant and abrupt change in channel alignment resulting in a new channel across the floodplain.

A chute cutoff is a type of meander cutoff that changes channel alignment on a smaller scale than an avulsion (*see Figure 2-17*). Chute cutoffs occur when the radius of curvature of a meander becomes so small that the flow shortcuts across the adjacent bar or floodplain, resulting in the development of a new meander pattern. Chute cutoffs may occur frequently in meandering river systems, and result in minor alterations to channel alignment which, when considered over time and space, may act to cumulatively change the overall channel pattern.

Chute cutoffs occur when the radius of curvature of a meander becomes so small that the flow shortcuts across the adjacent bar or floodplain, resulting in the development of a new meander pattern.

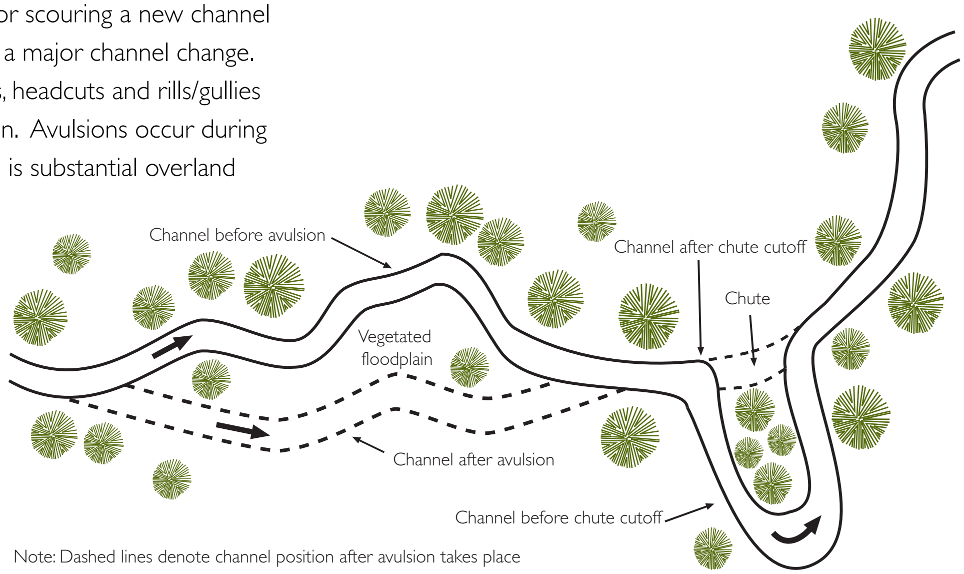

Figure 2-17. Avulsion and chute cutoff.

Though avulsions and chute cutoffs are natural processes, human activities are responsible for an increased frequency of their occurrence. Avulsions in particular may be caused by reach-based activities such as:

- aggradation (increased sediment supply and/or reduced hydrology),
- a downstream constriction,
- a large storm event,
- a braided channel, and/or
- channel relocation.

These causes are discussed in Chapter 3.

Floodplain activities may be a site-based cause of an avulsion. Removal of vegetation on the floodplain and/or in the riparian buffer reduces the shear strength of the soil and the roughness provided by vegetation to dissipate flow and energy. Floodplain mining of gravel is another activity that increases the risk of an avulsion. Placing roughness features in the floodplain, such as tree rows and or large, woody debris, will help dissipate the erosive energy.

Floodplain activities may be a site-based cause of an avulsion. Removal of vegetation on the floodplain and/or in the riparian buffer reduces the shear strength of the soil and the roughness provided by vegetation to dissipate flow and energy.

FIELD VISIT TO IDENTIFY AND CHARACTERIZE SITE CONDITIONS

Gathering data helps with analyzing mechanisms and causes of failure and the selection and design of streambank-protection techniques. An assessment form or information checklist can help cue the observer, and sketching the site conditions will provide geometrical information. Project site visits may be limited by time and season, available access, water stage and available equipment.

Characterizing site conditions involves identifying site conditions, collecting site data, looking for mechanisms of failure, developing a preliminary list of causes of failure, and estimating the frequency of erosion. *Table 2-2* is a checklist to assist in site characterization and to ascertain (or to rule out) the mechanisms and causes of failure.

Photos taken on a site visit should be from several perspectives, and it's a good idea to include objects in the picture that can be used to demonstrate scale of soils, bed material and streambank heights. Photos of the project site boundary can also help when designing transitions between the existing bankline and proposed streambank treatments.

After a site visit, further understanding of the project can be developed, incorporating:

- observation notes, sketches, photos and memories to characterize conditions at the site;
- preliminary identification of mechanism of failure;
- identification of frequency of failure at the site, and the aquatic habitat implications of this frequency; and
- preliminary identification of site-based causes of failure.

Conducting a reach assessment (see Chapter 3) will confirm the mechanisms of failure and identify whether there are any reach-based causes. For example, a site assessment may identify the mechanism of failure as erosion occurring at the toe. The site-based causes are identified as cattle accessing the river, resulting in vegetation disturbance and breakdown of the streambank. The frequency of this disturbance is annual; the habitat impact is deemed chronic. A reach assessment determines the stream reach is relatively stable and confirms there are no reach-based causes responsible for the toe erosion.

Conducting a reach assessment will confirm the mechanisms of failure and identify whether there are any reach-based causes.

Site Characterization Checklist

- ❑ channel geometry: cross section, streambank height, gradient, pool riffle system.
- ❑ planform: meander bend (how tight?), straight reach, physical features.
- ❑ over-bank topography.
- ❑ soils in terrace and bank.
- ❑ bed materials (bed substrate) and armoring (surficial material).
- ❑ woody debris abundance and location.
- ❑ geologic features.
- ❑ vegetation: species, abundance, location on streambank (lower vegetative limit).
- ❑ indication of the height of flood waters, or the peak erosive energy of such high flows; for example, lichen and moss limits on rocks indicating annual high water mark, debris collected in bushes indicating the height of a flood, and the size of cobbles on bars reflecting the maximum flow over the surface.
- ❑ location and depth of scour holes.
- ❑ flow patterns for existing conditions: flow direction, thalweg, angle of attack on streambank, impacts of physical features.
- ❑ approximate flow and stage at time of observation (e.g., during a flood, base flow, at bank-full flow).
- ❑ visualize flow patterns at higher or lower flows (something that may be difficult for the untrained or inexperienced observer).
- ❑ sediment transport indicators: bed-load caliber, bar formation, deposited material in eddies and backwaters, patterns in deposited sizes on bars.
- ❑ estimate channel roughness values.
- ❑ man-made features impacting flows: bridges, berms, armored streambanks.
- ❑ evidence of animal impacts.
- ❑ high-water features and ice scars.
- ❑ indicators of historical channel locations in the floodplain: channel scars or meander traces, exposed man-made structures, vegetation locations and deposits on terraces.

Table 2-2. Site characterization checklist.

DESIGN CONCEPTS OF SHEAR

After confirmation of mechanism of failure and reach- and/or site-based causes, the next step is to transition from a qualitative assessment to a quantitative assessment. The erosive forces acting on the streambank are quantified by calculating shear stress and the potential depth of scour (see Appendix E). With scour, we estimate the maximum depth of erosion that can occur; whereas with shear, we determine the magnitude of the erosive force. The calculation of both shear and scour are site-specific, although influenced by reach-based processes.

The shear stress on the streambank provides a measure of the erosive force that can be compared across different sites. Permissible velocity, the velocity a streambank can withstand before erosion occurs, has also been used as a quantitative measure. An advantage to working with shear, as opposed to velocity, is that it reflects the influences of the velocity and depth of the flow on erosion. If two channels with similar geometry, planform and gradient are flowing at the same velocity, the channel with the greater depth of flow will be subject to a greater erosive force at the bed and toe. A shear value will reflect this difference, while permissible velocity will not.

With scour, we estimate the maximum depth of erosion that can occur; whereas with shear, we determine the magnitude of the erosive force.

Fish are affected more by velocity than shear, as most fish do not live at the streambed surface; they seek areas of low velocity for residing. As shear increases to the point of moving particles, areas of low velocity diminish and eventually become areas of particle bombardment. It is valuable to recognize the role that shear stress distributions have on fish habitat utilization.[11] As shear increases, fish migrate to areas of lesser velocity or depth to avoid displacement downstream.[11] Thus, fish require habitat components along the stream channel margins.[19] When evaluating shear stress, consider the need for margin habitat equivalent in area to that lost to excessive shear. Refuge habitat is limited during flood events. Fish survival during high flows is dependent upon the hydraulic conditions that promote refuge habitat development.

VERTICAL DISTRIBUTION OF SHEAR

When designing streambank treatments, it is important to analyze both vertical and longitudinal distributions of shear. Once shear stress on the streambank has been calculated, this information can help select potentially successful streambank-protection techniques.

When designing streambank treatments, it is important to analyze both vertical and longitudinal distributions of shear.

Not all streambank-protection techniques have clearly quantified shear ranges, but there is adequate information available to assign a general range to many techniques.[20] Furthermore, since the erosional shear stress decreases progressively up a streambank (i.e., there is less shear higher up a bank), composite streambank treatments of various resistances can be applied at appropriate locations upstream on a streambank profile. Less rigorous techniques could be assigned to the upper streambanks, with more rigorous techniques applied in the lower streambanks.

Because depth and velocity vary in a channel, the shear stress acting on a channel bed and banks will also vary. In 1955, E.W. Lane[21] published the graphical representation shown in *Figure 2-18*. The figure shows how shear stress varies around the perimeter of a channel in a straight reach. The figure delineates erosive force decreasing higher up the streambank, which is a reflection of the reduced depth of flow over the streambank area. The understanding that shear stress is less at a higher elevation on the streambank is a key concept for bioengineering because it explains why it is not always necessary to armor a streambank from top to bottom. Bank-protection techniques that are less rigorous can be combined with hard-surface solutions when appropriate. In other words, riprap is not always necessary from toe to top of bank.

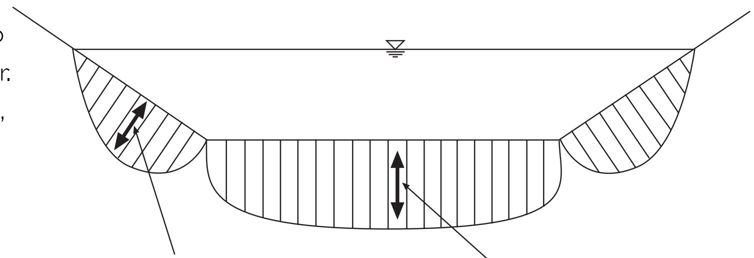

Figure 2-18. Typical shear-stress distribution in a channel.

Figure 2-18 illustrates why toe erosion is often subjected to greater forces than higher up the streambank and will exhibit more erosion. This diagram shows that the greatest shear on the streambank is approximately 78 percent of the shear acting on the bed, and the maximum streambank shear occurs up to the lower one-third elevation of the streambank.[11] This distribution of stress is known for a trapezoidal channel in a straight reach of the stream. A more recent and similar diagram is shown in *Figure 2-19*.[22] The bed shear stress calculations presented in the Appendix E can be transformed into the maximum streambank shear stress (acting approximately one-third of the distance up the bank) by multiplying by 0.78.

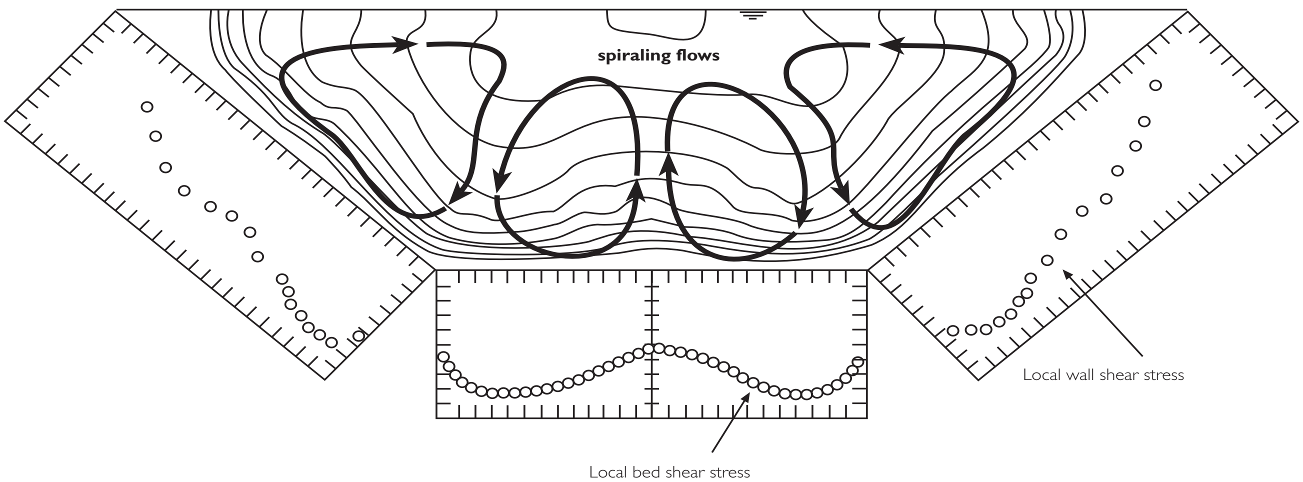

Figure 2-19. Shear-stress distribution in a channel, with primary velocities and secondary flow currents.

A geometric change in the channel shape causes a change in flow patterns, thereby varying the levels of shear stress. When flow goes around a bend or over an object, it no longer moves in a consistent pattern directed downstream in the channel. Flow moving around a bend begins to rotate sideways to the channel, generating a spiral motion. Established flow patterns not moving consistently downstream are described as secondary currents. In the bend, flow is moving sideways (spiraling), not moving prominently downstream. Surprisingly, the velocity of flow in this spiral motion exceeds the average velocity for flow moving consistently downstream. Since the flow velocity is higher, the flow has more erosive force and the capacity to move more sediment from the bed and banks of the stream.

CONCLUSION

In Chapter 2, we explored the various mechanisms of failure and their respective site-based causes. In Chapter 3, we'll examine the role that reach-based causes can have in mechanisms of failure and how they interact with site-based causes.

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